Glenn Research Center
Cleveland, Ohio 44135

Technical Support Package

Miniature Incandescent Lamps as Fiber-Optic Light Sources

NASA Tech Briefs
LEW-17820-1

National Aeronautics and
Space Administration

Technical Support Package

for

MINIATURE INCANDESCENT LAMPS AS FIBER-OPTIC LIGHT SOURCES

LEW-17820-1

NASA Tech Briefs

The information in this Technical Support Package comprises the documentation referenced in **LEW-17820-1** of *NASA Tech Briefs*. It is provided under the Commercial Technology Program of the National Aeronautics and Space Administration to make available the results of aerospace-related developments considered having wider technological, scientific, or commercial applications. Further assistance is available from sources listed in *NASA Tech Briefs* on the page entitled "NASA Innovative Partnerships Program."

For additional information regarding research and technology in this general area, contact:

Glenn Technology Transfer Office
Mail Stop 4-2
21000 Brookpark Road
Cleveland, OH 44135

Telephone: (216) 433-3484
E-mail:*TTP@grc.nasa.gov*

Miniature Incandescent Lamps as Fiber-Optic Light Sources

Brief Abstract

The invention consists of an incandescent lamp of tiny dimensions and method of fabricating. The re-entrant spiral filament is formed by wet chemical etch, laser ablation, or laser trimming. All methods use a 25 micron thick tungsten or tungsten alloy foil. The ends of the filament are vacuum brazed to gold contact pads within the ceramic package normally used for electronic chips. The package is closed with a transparent window normally used for ultra-violet erasing of volatile electronic memories. Because of the close proximity of the filament to the window, efficient direct coupling to fiber optics is possible without intervening optics.

Thus, a method for fabricating and packaging a robust broadband light source, capable of operating outside a vacuum chamber was developed. Several components comprising this device were developed, which include a tungsten filament, window, package, method for attaching the filament to the package, etc. Previously, a different packaging technique was developed to vacuum seal miniature tungsten filament light sources. This is described in patent #10-273,676.

Section I — Description of the Problem

A. Flight tests were performed in NASA GRC aircraft utilizing commercially-available light sources to interrogate optical sensors. Results of these tests indicated that the light source needed improvement in order to be widely utilized in flight.

B. These improvements include: lighter weight, lower input power, lower heat generation, ease of coupling to optical fibers, rugged, short stabilization time, and low cost. There is also a need for a broadband light source for calibration of space or airborne instruments. Similarly, the light source must be low power, rugged, and small.

C. Prior art includes commercially available whitelight sources. The device that most closely meets the needs described above is the LS-1 available from Ocean Optics, Inc.

D. Disadvantages of prior art include: high electrical power input, large amount of heat generation, long stabilization time, and large size.

Section II — Technical Description

A. Provide a small, low-power, stable white light source.

B. Tungsten filament capable of operating up to approximately 2,800 K, Window package, etc.
Package fabrication and hermetic sealing steps:
1) Use appropriately sized Leadless Chip Carrier (LCC) packages such as Kyocera Drawing number PB-C88231-JMI. The spacing of the contact pads should be approximately 0.25 inch so that the filament fits between two of the contacts. 2) Use windowed lids with solder preform (80Au-20Sn preform) for the LCC such as Spectrum Semiconductor Materials PN CLG39001. 3) Place braze preform Incusil-ABA over two opposing contacts on the LCC (incusil-ABA active braze material from Morgan Advanced Ceramics/Wesgo Metals 510-491-1100:Ag-59, Cu-27, In-12.5, Ti-1.25, liquidus temp = 715 °C). 4) Place filament on the braze preform. 5) Place in vacuum furnace (10^{-7} Torr) or furnace with inert atmosphere and heat to ~800 °C or until braze melts and wets filament metal. 6) Cool and allow to harden, bring back to atmospheric pressure. 7) Make a small nick in solder preform to allow air to escape and place lid on package. 8) Replace package with lid (with a weight or clip, if

necessary) to hold lid in place, into vacuum furnace and pump down to desired vacuum. 9) Heat furnace to solder eutectic temperature to melt and reflow solder. Cool to room temperature and bring back to atmospheric pressure. 10) Optionally a bake out of the filament can be done in vacuum chamber by applying electrical power before placing lid on LCC.

C. Operation is simple and not different from other incandescent lamps. A small voltage is applied that produces a small current. This current heats the filament and causes it to glow. The output color (and operational temperature) is directly proportional to the input current, providing a low-cost, low-power illumination source.

D. The filament has been fabricated by chemical etching as well as by laser ablation. Other types of packaging such as sealing into a glass bulb is possible and may be useful for some applications. USPO 10-273,676.

E. Because of the flat geometry, the optical characteristics are distinct from many incandescent lamps that have a coiled three-dimensional character. Sealed filament is capable of emitting broad band radiation up to 2,800 K. See Golliher et al paper (Attachment B)

F. Input power 2 Watts, Dimensions: 11.5 mm × 11.5 mm × 2.75 mm, output power: approximately 1.5 lumens.

G. Constant voltage power supply capable of providing 0-10 volts/0-1 amp.

H. Because of its small mass, it is anticipated that the lamp should be quite rugged.

Section III — Unique or Novel Features

A. Novel or unique features:
(1)The filament is formed from sheet tungsten or tungsten alloy, brazed to support, close to window for good coupling to fiber optics.
(2) Spiral filament design.
(3) 2-D package
(4) Flat filament mounted close to window.
(5) Long filament lifetime.
(6) Small size and high tolerance laser machining or lithography processes conducted on metal alloy foil were required to fabricate device repeatably and with reasonable cost.

B. Advantages of innovation: Low-power, low-cost, low-volume, stable, high operating temperature source. Designed for coupling into optical fiber, no lenses required. Filament: Consists of several quasi-concentric winds. Winds with greater radii are referred to as outer winds. Winds with lesser radii are referred to as inner winds. The occurrence of electrical short paths is undesirable among filament winds because it creates local over-currents which:
(1) skew the output temperature profile
(2) increase the evaporation rate of the filament which shortens operational lifetime and
(3) create an oscillatory temperature profile as the shorts were often intermittent.

The true white light provided by these devices overcomes limited wavelength output of LED's, thus increasing their applicability in spectroscopy. Benefits and uses of this device includes the following:

- Reduced heat production compared to state-of-the-art tungsten halogen sources
- Low input electrical power

- Device directly coupled to an optical fiber, and can be used to optically power a wide-range of fiber-optic sensors
- Currently no light sources meet Space Exploration missions needs
- Calibration source for spectrometers
- Light source for optical sensors
- Dual use as Illuminator/Micro-heater
- Miniature/Lightweight Device (10×)
- Ease of coupling to optical fibers (Important)
- Low-input Electrical Power (4×, 1.5 W v. 6.5 W)
- Increased Reliability (vibration)
- Stabilization time reduced (1,800×, <1 s v. 30 min.)
- Stable spectral output (feedback)

C. Development: Due to its small size, the response is much faster than larger commercial units. Heat stresses on such a small device can be significant causing electrical short paths. Through a combination of techniques, the reliability of the filament was increased in terms of lifetime and output stability. (Attachment C - NEPP Final Report)

D. Test data and source of error: Operated in tungsten filament in lab at up to 2,650 K and Tungsten-Rhenium at 2,725 K. Sources of error could be calibration of test multimeters, measurements of distance of calibration source and device from reflecting panel, optical path difference causing spikes in curves. The source has been operated up to approximately 2,800 K.

E. Analysis of capabilities: table radiation from visible to short IR wavelengths tested (due to spectral limitations of equipment on hand)

Section IV — Potential Commercial Applications

Can be used for both Lunar and Mars Missions

- Replace use of moon as calibration source (provides calibration on demand)
- Calibration source for spectrometers
- Optical source
- Mars Mission – currently being evaluated for robotic mission (2012)
- Characterization of Mars Atmospheric Dust –illumination of dust for characterization with spectrometers.

- Needs to be commercially available
- Needs to be space qualified.

Attachment B

THERMAL ANALYSIS OF A MEMS BASED BROADBAND LIGHT SOURCE: TEST DATA AND MODEL

Eric L. Golliher[1], Margaret Tuma[1], Joseph Collura[2], Eric Jones[3], James Yuko[1]

[1]NASA Glenn Research Center
21000 Brookpark Road
Cleveland, Ohio, 44135
Phone: (216) 433-6575
Email: golliher@grc.nasa.gov

[2]John Carroll University
20700 Northpark Blvd.
University Heights, OH 44118
Email: jcollura@jcu.edu

[3]Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109
E-mail: eric.jones@jpl.nasa.gov

ABSTRACT

NASA Glenn Research Center, the Jet Propulsion Laboratory and Lighting Innovations Institute at John Carroll University are developing a MEMS-based, low-power, incandescent broadband light source for aeronautics and spacecraft applications. This paper summarizes a thermal analysis of the MEMS package and filament. The packaged device is very small, measuring approximately 1.2 mm thick, 15 mm long, and 10 mm wide. This device can be used to interrogate optical sensors or as a calibration light source for spectrometers. Several alternating layers of Silicon, Silicon Nitride, Silver Oxide, and Titanium/Platinum/Gold build the basic mechanical structure. A square cavity in the center of this "box" suspends a spiral Tungsten filament. The filament emits light and heat like a black body at about 2650 K that bounces off the reflective walls of the cavity and exits through the Silicon Nitride window at the "top" of the structure. Temperature requirements, analysis methods and results are discussed. The analytical results are compared to recent laboratory test data.

KEY WORDS: blackbody, power, Silicon, Tungsten

NOMENCLATURE

A	Area, m^2
r	Radius of spiral, microns
t	Thickness of filament, m

Greek symbols

σ	Stefan-Boltzman constant, $W/m^2 \cdot K^4$
ε	Emittance
$\dot{q}$	Heat Generation per unit volume, W/m^3
k	Thermal Conductivity, W/mK
x	Length Along Filament, m
T	Temperature, K
ρ	Electrical resistivity (micro-ohms-cm)
θ	Spiral angle (radians)
A_x	Area perpendicular to the x direction, m
w	Filament width, m

INTRODUCTION

The development of a MEMS-based broadband lightsource has many technical challenges. The thermal design of the device was identified as critical to reliability and robustness [1]. This paper is concerned with the thermal analysis of the filament, fabricated by The Aerospace Corporation, and the associated portion of the package near the filament. Test data of a filament is compared to preliminary thermal analysis results. Further package level thermal analysis shows the impact of the hot filament on the Silicon structure.

The innovation described in this paper is intended as a low power broadband calibration light source for advanced optical sensors. Such a microsize lightsource would dramatically decrease power consumption of state-of-the-art calibration devices and therefore lead to easier integration to space vehicles. The limiting parameter for the current design is the attachment point of the filament to the package, which must be kept below 450 °C to avoid melting the solder material.

There were two separate analyses performed. The first was an analysis of the filament in a test fixture for the purpose of correlating a simple thermal model to test data. The second was a simple three-dimensional analysis of a package to show the impact of the hot filament on the Silicon package.

Functional details of this concept have been discussed in a past publication [1]. The thermal analysis of a preliminary design completely omitted the filament thermal requirements and focused on the temperature prediction of a micro detector intended as a feedback loop to monitor the light [2]. At that time, the detector temperature requirements were the limiting factor in assessing the thermal integrity of the design. With the present design, it is felt that the filament will now be the limiting factor in the overall package thermal design.

MODELING TOOLS

Systems Improved Numerical Differencing Analyzer (SINDA) is a very popular tool used in common spacecraft thermal analyses. In spacecraft thermal design analysis, heat conduction and radiation are the dominant heat transfer mechanisms. SINDA is optimized for finite difference solutions to these types of problems on a spacecraft level. This paper is an interesting demonstration of the use of SINDA on a MEMS level. There are several versions of SINDA, and the one from SpaceDesign was chosen for convenience [3].

FILAMENT GEOMETRY AND MODEL

The tungsten filament, as shown in Figure 1, is shaped in a double spiral coil to provide a bright uniform light "point" source. The relationship between radius and spiral angle is

$$r = \frac{100\theta}{\pi} \tag{1}$$

The filament is 50 microns in width and 25 microns in thickness, with a 1.5 cm uncoiled length. For thermal analysis purposes, this can be assumed a straight line with total length 1.5 cm. The double spiral is symmetrical about the central point. The hottest point will be in the center of the 1.5 cm filament. A close examination of the filament geometry shows there is a length difference of about 18% between the outer wall filament path length and the inner wall filament path length. The outer path length calculates to be 1.649 cm and the inner path length 1.367 cm, yielding an average path length of 1.5 cm. It was the average path length that was used in this one-dimensional thermal analysis of the filament.

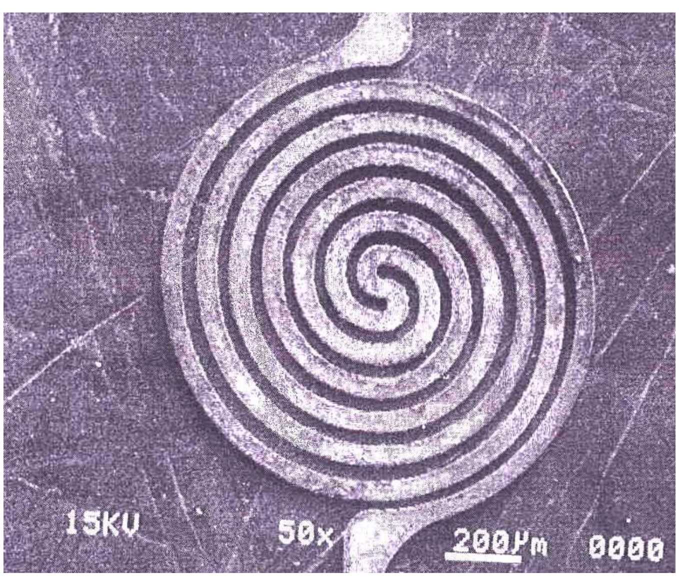

Figure 1. Scanning Electron Micrograph of the Filament

FILAMENT ANALYSIS

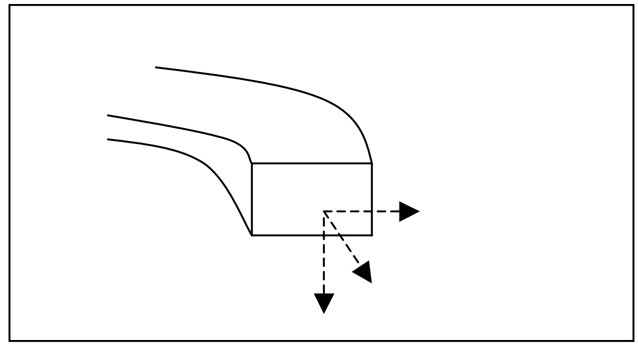

Figure 2. Coordinate System for Thermal Analysis

The temperature gradient of the thin filament in the z or y directions as shown in Figure 2 is negligible compared to the temperature gradient in the x direction. The maximum length in the y direction is 25 microns, and the maximum length in the z direction is 12.5 microns. The x direction is along the length of the filament with x = 0 at the center and x = 0.75 cm at the end of the spiral, as shown in Figure 3. As justification for this assumption, a calculation shows that the external radiation thermal conductance in the y or z directions, is small compared to the internal thermal conductance [4].

$$\frac{\sigma\varepsilon T^3 y}{k} \ll 1 \tag{2}$$

$$\frac{\sigma\varepsilon T^3 z}{k} \ll 1 \tag{3}$$

Thus, the only significant thermal gradients within the filament will be those along its length.

The analysis assumes steady state conditions. The governing equation for the filament is adapted from Carslaw and Jaeger [5] for a thin, high temperature wire carrying electricity as

$$\frac{d^2T}{dx^2} - \frac{\varepsilon 2w\sigma(T^4 - T_o^4)}{kA_x} + \frac{\dot{q}}{k} = 0, \tag{4}$$

with boundary conditions $\frac{dT}{dx} = 0$ at x = 0,

and $T =$ 36 °C at x = 0.75 cm,

where

$$\dot{q} = f(T) \tag{5}$$

$$k = f(T) \tag{6}$$

$$\varepsilon = f(T) \tag{7}$$

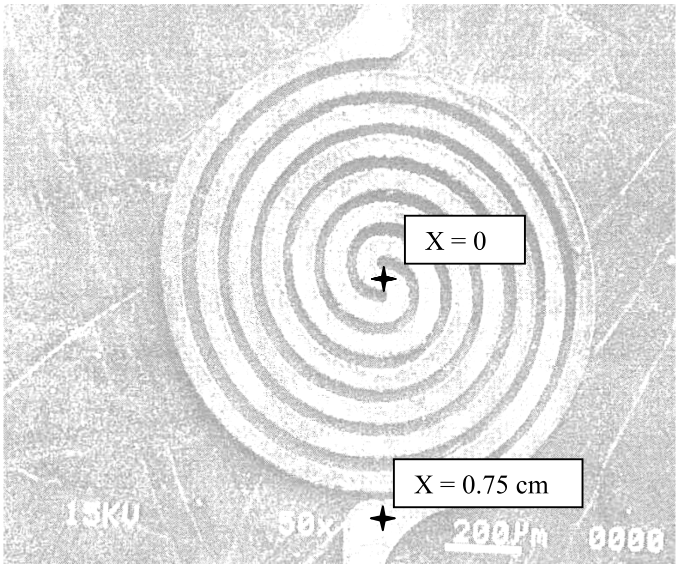

Figure 3. Thermal Analysis Coordinates on the Spiral

The filament symmetry required that only one half of the filament be modeled. Since the expected temperature range was from 2650 K to room temperature, temperature dependant properties of thermal conductivity, thermal emittance, and electrical resistivity were used.

The model divides the 0.75 cm length into 20 nodes. SINDA uses a standard finite difference scheme to solve the conduction and radiation problem. Since the test occurred in vacuum, no convection analysis was necessary. The vacuum chamber was at about room temperature, so the radiation heat sink, T_o, was held to 21 °C. Since the SINDA model only included one half of the filament, the temperature of one end of the filament represented the filament center and was allowed to come to equilibrium. The temperature of the other end was held to 36 °C. The fixture block was tactilely estimated to be at a temperature on the order of 30 C suggesting that the block was in lesser thermal contact with the chamber than expected. The estimated 6 °C difference was considered to be much less than the 2650 K filament, so the model's 36 °C constraint was considered to be valid for correlation with the test data.

For future test data with possibly different filament geometries, the attach point temperature will be monitored with a small gauge thermocouple. The thermal contact resistance was assumed zero, since the contact pressure of these clamps was very high. The heat load was applied to each node as a function of the independent variable, current.

In the model, the independent variable, current, was adjusted until the thermal model current value matched the test value. Then, a heat balance was performed on the radiation and conduction heat transfer from the filament to determine the total heat loss predicted by the model. This was compared to the test electrical power measured during the test. Next, the model prediction of filament temperature was derived from a fourth power average of all the individual nodal temperatures that were above the sensitivity of the Ircon Thermometer, 1500 °C. Then, this average filament temperature was compared to the test temperature recorded by the Ircon thermometer. Temperature dependent properties include conductance, electrical resistance, and emittance of Tungsten.

For thermal conductivity, Figure 4 shows that including temperature dependant properties are necessary, since the variation is large over the temperature range of interest.

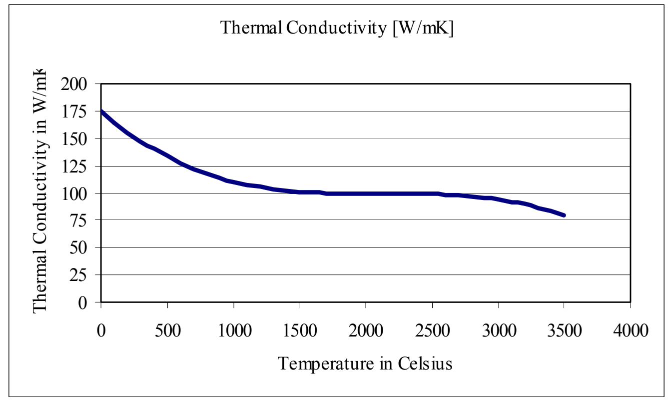

Figure 4. Plot Showing Tungsten Filament Thermal Conductivity Variation with Temperature

Heat generation is a function of temperature since Tungsten electrical resistivity varies with temperature substantially from 21 °C to 2650 K [6]. The temperature polynomial that describes this dependence is given below:

$$\rho = 4.6122+2.4498*10^{-2}\,T+3.5628*10^{-6}\,T^2 -1.9686*10^{-10}\,T^3$$

Thermal radiative emittance of Tungsten is also a function of temperature [7]. It is approximately linear from 0.022 at 21 °C to 0.334 at 2727 °C.

Radiation thermal analysis assumed temperature dependent gray surfaces. The only radiating surfaces were the top and bottom of each filament section. Radiation between the filament segments to other filament segments was neglected, since the temperatures are nearly the same, and the principal path of radiation heat transfer is from the filament to the ambient surroundings at 21 °C. Thus, by using this approach, complicated radiation exchange factors representing heat transfer between the coil segments is not needed, and the model is very much simplified.

FILAMENT TESTING

The temperature of the filament was measured with an infrared thermometer, Ircon Modline 3R-35C15 [8], with the spectral region chosen to detect temperatures from 1500 °C to 3500 °C. The sensor uses a ratio radiation two-color technique to determine temperature.

Testing of the filament took place under vacuum with the filament structure firmly clamped between two electrodes that are shown in Figure 5.

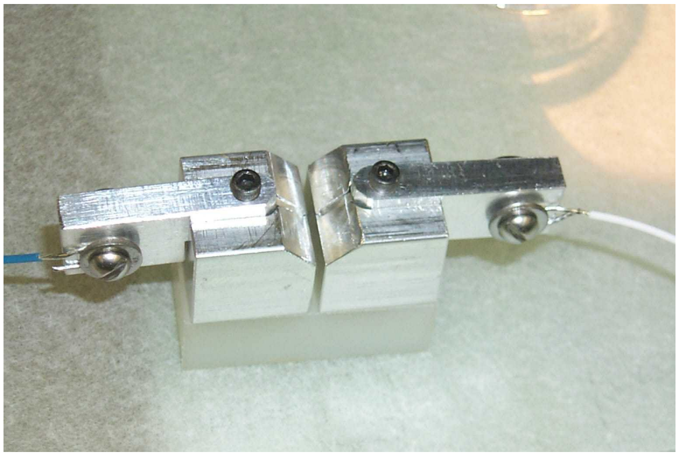

Figure 5. Filament Test Mounting Fixture

PACKAGE GEOMETRY

The package geometry for a candidate design is shown in Figure 6. Although not to scale, relative positions of the window, filament and Silicon package are apparent.

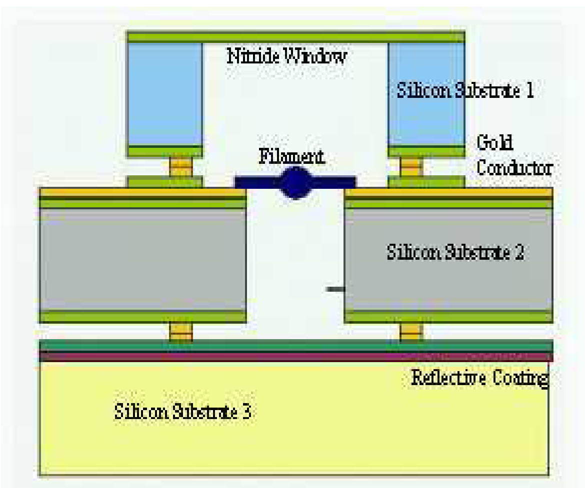

Figure 6. MEMS Package and Filament Geometry

The packaged device measures approximately 1.2 mm thick by 8 mm length and 5.4 mm width. The top of the device is covered by a thin (2.5 micron) Silicon Nitride (Si_3N_4) window, which is transparent to light. Several alternating layers of Si_3N_4 and Silicon (Si) form a sandwich structure that provides support for the filament, the Si_3N_4 window, and the electrical interconnects.

PACKAGE ANALYSIS

After a suitable model of the filament was obtained, the effect of the filament upon the package was determined. The package analysis was an application of SINDA in a three-dimensional conduction problem with temperature dependent conductivity. The package bulk temperature was expected to be near room temperature except for a local hot spot near the filament attach point. The symmetry of the problem required that only one quarter of the package be modeled to adequately map the heat flow within the package. Thermal radiation was neglected, as this would give a maximum worst case hot spot on the package filament attach point. The amount of heat dissipated by the filament was applied to the attach point of the package. The bottom surface of the package was held to 21 °C. The two separate models were iterated until the attach point temperature and heat flow agreed in both models. In the package analysis, the filament attach point temperature was allowed to vary, and the resulting temperature was used as the input to the filament analysis.

This assumption of a fixed room temperature boundary condition of 21 °C is valid, since the attach point to a spacecraft would most likely be the spacecraft main bus or main payload structure. With the small heat load of this device, the spacecraft structure temperature would most likely be unaffected and act as an infinite "heat sink". Room temperature is not an unreasonable assumption for spacecraft structure that is well insulated and in good thermal contact with the internal spacecraft environment. When actual spacecraft integration occurs, real "cold case" and "hot case" boundary conditions will be established.

RESULTS

Table 1 lists the model results versus the test data. It appears that the filament modeling is successful, as the test data matches the computer model results fairly well. Figure 7 shows the temperature versus filament length from the center of the filament to the edge attach point, as predicted by the model. A fourth power averaging scheme for each nodal temperature in the Ircon sensor range was used to get a representative average filament temperature. This was necessary because the infrared thermometer sensor measures the average temperature of the source, and is sensitive only to radiation between 1500 °C and 3500 °C [8].

Table 1. Filament Analysis Results

	Test	Model	Delta [%]
Power [Watts]	1.334	1.383	3.7
Temperature [°C]	2276	2340	2.5
Current [Amps]	0.4123	0.4123	N/A

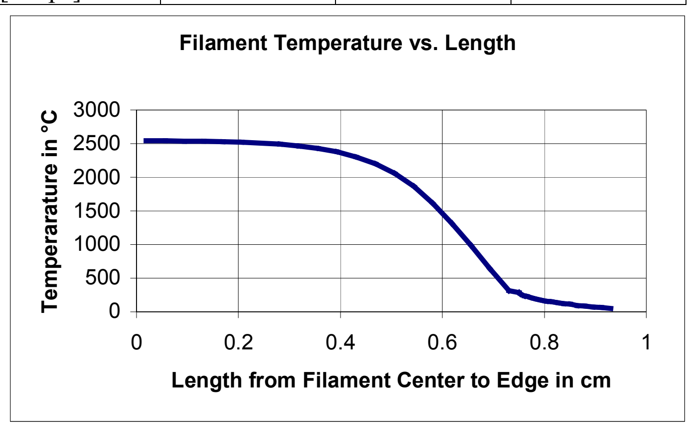

Figure 7. Temperature Plot as the Filament Spirals Outward

The package analysis showed that the filament attach point will be well below the 450 °C requirement. The attach point predicted temperature is 36 °C. This was subsequently used in the filament analysis as a boundary condition. The attach point is shown in Figure 8 as the hotspot near the corner.

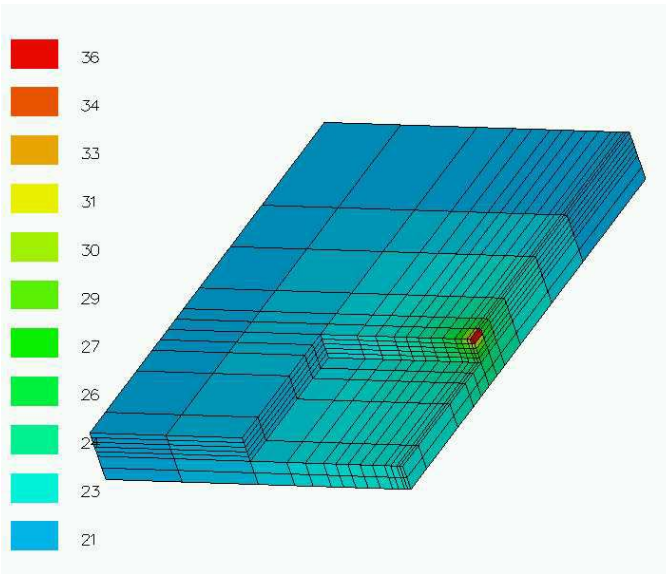

Figure 8. Package Analysis Results in °C

CONCLUSIONS

Common thermal analysis codes appear to be adequate to predict temperature results of MEMS devices on this scale. With the assumptions made here, the device will not exceed temperature requirements. Radiation modeling that only includes the top and bottom of the filament surface appears to be a valid approach. This greatly simplifies the thermal model thereby saving computational time and modeling effort. Also, the model provides a prediction of temperature versus filament length, something that is not available from testing due to instrumentation limitations.

SUMMARY

This paper has demonstrated the use of a standard thermal code to analyze and provide design recommendations for the development of a MEMS-based broadband light source. Although the small dimensions encountered in this problem are not typical of those solved by spacecraft thermal engineers, a thermal code typically used in spacecraft thermal analysis (SINDA), can be used. It appears that no microscale heat transfer effects are present. Since the data matched the thermal analysis predictions within an acceptable margin of error, it appears that a relatively simple thermal model is all that is needed to adequately predict current, power and temperature of the filament in the test fixture. Further thermal modeling and test data comparison is planned in the near future, as more test data becomes available. The model will be exercised for various filament designs and manufacturing techniques. As such, this report validates only a thermal model of a preliminary design, but indicates that the thermal modeling approach is sound.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the research of Sue Wrbanek at NASA Glenn Research Center (GRC) and Drago Androjna of AKIMA, whose efforts made the Scanning Electron Micrographs of the Tungsten filament available for this report.

REFERENCES

[1] M. Tuma, et al., “MEMS Incandescent Light Source,” Proc. *SPIE Annual Meeting: Photonics for Space Environments VIII* (AM106) San Diego, CA, 2000.

[2] E.L. Golliher, “Thermal Analysis of a MEMS Broadband Lightsource,” Proc. *11th Thermal & Fluids Analysis Workshop*, Cleveland, Ohio, August, 2000.

[3] J. Clay, “TSS User’s Guide,” www.spacedesign.com.

[4] F. Incropera and D. DeWitt, Fundamentals of Heat and Mass Transfer, John Wiley & Sons, 1985.

[5] H.S. Carslaw and J.C. Jaegar, “Conduction of Heat in Solids Second Edition,” pp.149-161, Oxford Science Publications, 1988.

[6] J. Davis, ITER Materials Handbook, http://aries.ucsd.edu/LIB/PROPS/ITER/AM01/AM01-0000.html.

[7] Y. S. Touloukian and D.P.DeWitt, “Thermophysical Properties of Matter,” IF/Plenum Publishing, 1970.

[8] Ircon, Inc., “Modline 3 Infrared Thermometer Installation/Operation Manual,” IRCON, Inc., Niles, Illinois, March 2000.

Attachment C
NASA MEMS Broadband Lightsource 2002 Annual Report

Version-012

Joe Collura

Physics Department, John Carroll University, University Heights, OH, 44118, USA

September 2002

Abstract
The laser-ablated spiral Tungsten (W) filament (wfil-laf2) and chemically-etched spiral Tungsten (W) filament (wfil-grc1) of a Micro Electrical Mechanical System (MEMS) broadband lightsource was evaluated. A number of filaments have been run at ~2000K for ~1000 hours each, which was the goal. A smaller number of filaments than expected were tested due to equipment failures. The filaments in the single filament fixture were run under 1e-06 torr of vacuum. The filaments in the 5 filament fixture were run under 1e-05 torr of vacuum due to a failing vacuum pump. The voltage, current, and temperature were measured. Design changes were suggested and then implemented in a low quantity production run.

Apparatus
The original Pfeiffer vacuum pump mvp035-2 failed during Q1-FY02. It was replaced under warranty with another mvp035-2. The replaced mvp035-2 failed during Q4-FY02 out of warranty. The second failed Pfeiffer mvp035-2 is in the process of being replaced with a Pfeiffer mvp055-3c. The mvp055-3c was chosen under the expectation that the mvp035-2 series was having design or manufacturing problems. (The manufacturer has since noted a higher than expected failure rate with the mvp035-2 pumps). The reason for staying with Pfeiffer after 2 consecutive bad pumps was that the Pfeiffer Turbocube® as a whole performed rather well and was simple to operate. (The Turbocube® consists of a membrane coarse vacuum pump, a turbine fine vacuum pump, a power supply, and a control unit). Since we were staying with Pfeiffer we retained return value on the second failed mvp035-2 pump and simplified integration of a replacement pump into the rest of the Pfeiffer turbo cube of which the pump was a part. By replacing the mvp035-2 with an mvp055-3c we expect to be able to get quicker pumpdown times, and along with various hose and flange changes we should be able to work with corrosive vapors (allowing a possible halogen cycle in the lamp package which could give a more consistent optical power output as a function of long-term time by scavenging evaporated tungsten off of the package window and depositing it back onto the filament).

Observations
The 2002 fiscal year was somewhat successful. Even with the loss of 2 separate Pfeiffer mvp035-2 membrane vacuum pumps, we still obtained about 2 respectable 1000 hour data runs. This is important as 1000 hours is the approximate duration target life for the

filament. The most impressively running filament to date was the wfil-grc1-20020412 as it didn't appear to have problems with shortened electrical paths and ran at ~2300Kelvin at ~0.9 electrical watt for ~1871hours at which point it was forced to fail. Forced failing was done by notably increasing the driving voltage until the filament was at ~2.75 electrical watt for ~2900Kelvin at which point it continued to burn for ~1 hour before failing. It appears that in comparison with the wfil-laf1 and wfil-laf2 series of laser ablated filaments that the wfil-grc1 chemically-etched filament is more stable. The wfil-laf2-12132001 run of ~2200Kelvin at ~1.25 +/-0.25 electrical watts for ~1445 hours was also a good proof of lifetime run. It appears that when comparing the temperature and electrical power stability as a function of time that the laser ablated filaments are noisier than the chemically-etched filaments. This difference is not evident to be due to anything particular to either of the fabrication processes. The difference does seem to correlate with the geometry of the filament. The laser ablated filaments were all designed with narrow interwinding spaces while the chemically etched filament was designed with a wider interwinding space. Note that the filament with the wider interwinding space had more consistent radiated temperature and electrical consumption.

The laf1 (75um wide winding / 25um interwinding space) and the laf2 (85um wide winding / 13um interwinding space) versions of the MEMS broadband lightsource filament exhibited coil to coil shorting and outer winding to supporting tab shorting of the winding across the interwinding space. Note that grc1 did not seem to have a problem with the outerwinding to support arm short. This may be because grc1 (50um wide winding / 50um interwinding space) had wider interwinding spacing than laf1.

The 5 filament fixture was run once, during which time the vacuum pump was not running at its optimal performance level (was 1e-5torr instead of 1e-6torr). That run of 5 filaments was over 3 of the oxygen process filaments (wfil-laf2-g13-O-20020715abc) and 2 of argon process filaments (wfil-laf2-g6-Ar-20020715de). Use of an oxygen cutting process could help cut production cost by increasing cutting speed and might produce better (smoother surface with lower cutting temperature) and/or worse (porous) surface properties. Aerospace and the lighting industry believe heavily in an oxygen process. The oxygen filaments seemed to be noticeably more likely to short out (and do so less predictably) than shorts exhibited by argon process filaments. The argon process filaments seemed more stable during this comparison. The oxygen process filaments in the test lasted from ~100 (a) to ~350 (b,c) hours at ~2300Kelvin at ~1.4 to 2.0 electrical watts. Only one of the argon process filaments in the test was at ~2300Kelvin from 0.75 to 1.5 watts and lasted for ~460 hours. It was not known what to expect from the oxygen in terms of performance because there was no prior oxygen process filaments in the project. The other argon filament was run in that range for only an hour and then was force failed where it ran for ~1hour at ~2700Kelvin at ~2.0 electrical watts due to failing pump time constraints. The argon process filaments groups in this test did not do as well as expected. This was presumably due to the vacuum problem but this was also the first non test run of the fixture. The filaments may not have been properly mounted. Regardless of this, the oxygen process filaments did seem less manageable in their current processing state.

A design revision producing laf3 series was conducted based on the observation of design traits and of operation traits of laf2 series filaments and of grc1 series filaments. The laf2 had narrow interwinding space which may be the reason it was more likely to have interwinding shorts. The grc1 had wide interwinding space which may have been reason it was less likely to have interwinding shorts. The laf3 series rev 000-010a was designed with interwinding space as wide as that of grc1 to reduce likelihood of interwinding shorts. Further, laf3 was designed to have the support tab retracted from its laf1/laf2/grc1 position to reduce the likelihood of the support tab to outer winding electrical path shorts. The source of the outerwinding to support tab short may be due to the fact that although the whole filament expands with temperature, the support tab is mechanically fixed. So, as the rest of the winding unspools toward the tab, the tab concurrently stretches closer to the outer winding. Eventually the two meet and a shorter electrical path is formed. It is expected that the revisions introduced in laf3 series will improve the lifetime and the short-term time consistency of the optical output by reducing the occurrence of winding-to-winding electrical short paths and winding-to-support tab electrical short paths. By reducing occurrences of short electrical paths we should get more consistent temperature along the coil. This should allow a lower maximum local temperature along the filament which should allow lower local evaporation rates which should give a longer life. Further, the outboard ends of the support tabs were shortened to allow better fit into the package. A small quantity production run was performed by Aerospace Corporation producing 3 of the laf3 series rev 000-010a filaments. The 3 filaments will be tested before a 100 piece production run is performed by Aerospace.

Filament Designation	Time of Life (Hour)	Radiated Temperature (Kelvin)	Electrical Power (Electrical watt)
WFIL-LAF2-12132001	~1445	~2200	~1.25
WFIL-GRC1-20020112	~1871	~2300	~0.9
Then force failed at	~1	~2900	~2.75
WFIL5-20020715-A: (LAF2-G13-O2)	~100	~2300	~1.4
WFIL5-20020715-B: (LAF2-G13-O2)	~350	~2300	~1.5 to 2.0
WFIL5-20020715-C: (LAF2-G13-O2)	~350	~2300	~1.4
WFIL5-20020715-D: (LAF2-G06-AR)	~460	~2300	~0.75 to 1.5
WFIL5-20020715-E:	~1	~2300	~1
(LAF2-G06-AR)	~1	~2700	~2

Filament Series	Material	Manufacture Process	Geometry
LAF1	Tungsten(1)	laser ablation	75um wide winding 25um intrawinding space 25um thick
GRC1 (CEF2)	Tungsten(1)	chemical etch	50um wide winding 50um intrawinding space 25um thick
LAF2	Tungsten(1)	laser ablation	85um wide winding 13um intrawinding space 25um thick
LAF3	Tungsten(2)	laser ablation	50um wide winding 50um intrawinding space 25um thick

Note 1. The tungstens used were either pure or potassium doped
Note 2. The tungstens used were either pure or 3 percent rhenuim doped

Figure 0. NASA SEM of WFIL-LAF2 series filament